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THE REFLECTION AND RADIATION OF SOUND FROM DUCT OPENINGS IN HVAC SYSTEMS

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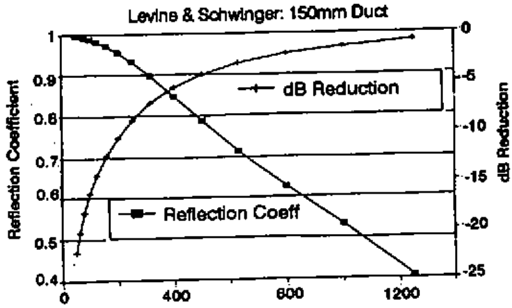
1. Introduction

The change in acoustic impedance which occurs at the end of a duct causes some of the sound energy to be reflected back down the duct thus reducing the noise emitted from the duct opening. The end reflection loss, E in decibels, is related to the amplitude reflection coefficient, r, by the relationship : $E = 10 \log(1 - r^2)$

The effect is related to the wavelength and to the dimension of the duct. Figure 1 shows the reflection coefficient predicted by the theory of Levine and Schwinger (1) for an infinite circular duct of 150mm diameter. Also shown on the graph is the corresponding end reflection loss, in dB, which is large at low frequencies, when the reflection coefficient is very close to unity. This can be very useful to designers of HVAC systems as it gives valuable attenuation in a range which is generally difficult to control and would otherwise need large passive silencers.

Figure 1



2. Prediction Of End Reflection Corrections

The Table below shows examples of predicted end reflection loss for a 150mm circular duct from ASHRAE , AMCA , CIBSE and BS878: Part 2: 1985, Methods of noise testing for fans, and from the Levine and Schwinger theory.

Freq. (Hz)	ASHRAE	AMCA	CIBSE	BS878	L & S
63`	18	18	15	>20	21.2
125	12	12.5	11	15	15.4
250	8	7.5	7	9.5	9.7
500	4	3.5	3	5	4.9
1000	1	1	1	1.5	1.8

Previous work on end reflection, including the bases for the above predictions, has been reviewed elsewhere (2,3). There is some discrepancy between the various prediction methods, and they also give differing advice about when the end correction should be applied. ASHRAE recommends their application only when the duct is of length greater than 3 to 5 times its cross-sectional dimension, and that if a diffuser is used the correction should be reduced by 6dB. Reynolds and Bledsoe comment that there is limited experimental data on end reflection effects, and it would seem that further research is required, especially on the effect of grilles and diffusers, duct length and aspect ratio, and flow and source conditions.

3 Measurement Of End Reflection Coefficient

This may be obtained from measurements of the standing wave ratio in the duct, for pure tones, or using broad band signals in which the transfer function between two positions in the duct is determined using either a one or two microphone technique.These methods have been decribed and compared in a previous paper (3)

Measurements have been carried out to compare the different methods and to investigate the effect of duct length In order to measure a large reflection effect, a small duct was used of square cross section (100mm by 100mm), 2m long, made from melamine-faced chipboard, 12mm thick that was stiff enough to minimise duct breakout. A loudspeaker was used as a noise source.

The standing wave ratio method results show good agreement with theory except at the lower frequency range, when the reflection coefficient tends to unity. This may have been because the true standing wave ratio was higher than the signal-to-noise ratio.Results from the two and one microphone transfer function methods, using a dual channel FFT analyser to measure the magnitude and phase of the required function are compared alongside Levine and Schwinger's theory, in Figure 2. The results from the two microphone technique is closer to the theory below 1000Hz. This may be because the fixed microphone spacing can be measured more accurately than the difference moved by the travelling microphone.

The reflection coefficient of ducts of 0.1m, 0.2m, 0.5m, 1m, and 2m in length have been investigated, using the two microphone method. Figure 3 shows that the results are close and do not show any correlation with duct length, with even very short lengths of duct appearing to give a large end reflection loss. This would seem to conflict with ASHRAE's advice that end reflection reduction should not be applied to ducts shorter than 3 to 5 duct diameters.

Figure 2

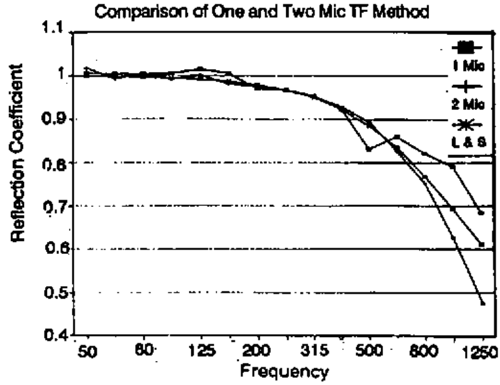
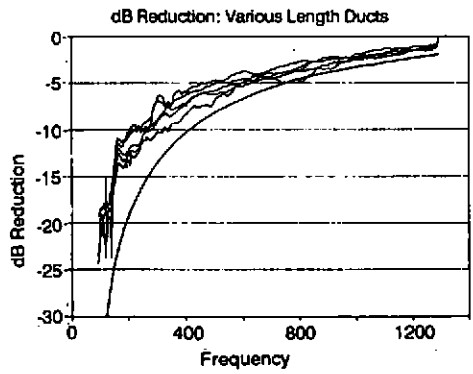


Figure 3



4. The Reflected Energy

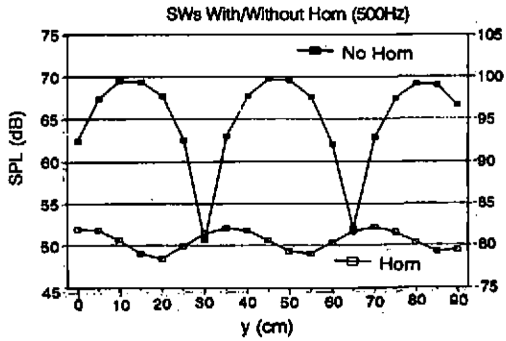
Calculating the loss directly from the reflection coefficient does not tackle the important question of what happens to the reflected energy. It assumes that it is all carried back down the duct and has no influence on any other part of the system. However, the conditions downstream of the duct opening must influence what happens to this reflected energy and so affect the total energy radiated from the termination. A silencer downstream of the opening might absorb most of the reflected energy and produce a similar effect to an infinitely long duct, whereas a bend might reflect much of this energy back towards the opening, where some will be radiated and some will undergo further reflection.

Direct measurement of the end reflection loss is difficult because the reflected energy causes standing waves (Fig.4) which complicate the measurement of in-duct sound power. The use of either anechoic or acoustic horn terminations will reduce the reflections, but may alter the acoustic load presented to the loudspeaker or fan and so change its output, as indeed will varying the length of the duct. Figure 4 shows the standing wave pattern measured for a pure tone in the duct with and without a horn (0.5m in length and of outlet dimensions 350mm x 50mm) on the outlet. However, to work satisfactorily down to the lowest frequencies of interest the horn would have to be impractically large.

5. Interaction with other attenuation mechanisms

Existing prediction methods for HVAC noise (2,4) simply aggregate various the components of system attenuation, including the end reflection loss without considering any interaction between them. They assume that the sound pressure level along a duct length reduces at a constant steady rate due to attenuation mechanisms. If, however, end reflections occur, as Figure 4 shows, the standing waves produced will result in a very non-uniform distribution of sound pressure level and will affect, for example, calculation of duct attenuation and breakout.

Figure 4



6. Conclusions

Measurement of open-end reflection coefficient, by different methods, for a small square cross section duct agree reasonably well with the theory for an infinite circular pipe of equivalent area. The reflection coefficient did not vary significantly with duct length. There is uncertainty as to how the end reflection correction factor should be applied in many practical situations, and how it will interact with other components of system attenuation, and there is a need to measure and relate in-duct and radiated sound power.

References

1. H. Levine, J. Schwinger, Physics Review, pp 383-406, (1948)

2. D D Reynolds, J. M. Bledsoe, Algorithms for HVAC Acoustics, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Research Project 446-RP.(1991)

3. R J Peters, C J McCambridge, Proc. IOA Vol 17 Part 4 , pp 217 - 229, (1995)

4. R J Peters, Proc IOA Vol 17 Part 4, pp 487 - 498, (1995)